

# **WHAT IS CLAIMED IS:**

1        1.        A method of starting an internal combustion engine, wherein the engine includes a  
2        plurality of cylinders each containing a piston which is mechanically connected to a  
3        crankshaft, and wherein the engine is configured to operate with a predefined normal firing  
4        order, the method comprising:

5                selecting at a cylinder for initial firing, selection of the cylinder based upon the piston  
6        of the cylinder being located in a predetermined position along its stroke;

7                injecting fuel into the selected cylinder to create an uncompressed fuel-air mixture;

8                igniting the uncompressed fuel-air mixture in the selected cylinder;

9                repeating said selecting, injecting and igniting until there is sufficient kinetic energy  
10       to complete a compression stroke in at least one of the cylinders, the selecting being made as  
11       a function of cylinder piston position without regard to normal firing order; and

12               after completion of a compression stroke, firing the cylinders according to the  
13       predefined normal firing order.

1        2.        The method of claim 1 further comprising:

2                adjusting a dynamic compression ratio of the selected cylinder by adjusting valve  
3        event parameters of the selected cylinder prior to firing the cylinder according to the normal  
4        firing order.

1        3.        The method of claim 1, wherein the predetermined piston position of the cylinder  
2        selected for initial firing is a position where the piston has sufficient mechanical advantage to  
3        rotate the crankshaft through at least 180 degrees in response to igniting the mixture in the  
4        first selected cylinder.

1        4.        The method of claim 3, wherein the predetermined piston position of the cylinder  
2        selected for initial firing is a position selected to have sufficient mechanical advantage to  
3        rotate the crankshaft in a counter-clockwise direction.

1        5.        The method of claim 3, wherein the predetermined piston position of the cylinder  
2        selected for initial firing is a position selected to have sufficient mechanical advantage to  
3        rotate the crankshaft in a clockwise direction.

1        6.        The method of claim 3 wherein the predetermined piston position of the cylinder  
2        selected for initial firing is in a range between 25 and 155 crankshaft degrees after top dead  
3        center.

1        7.        The method of claim 1, wherein after igniting the cylinder selected for initial firing,  
2        the piston of the selected cylinder moves towards bottom dead center.

1        8.        The method of claim 7 further comprising:  
2                opening an exhaust valve when piston moves away from bottom dead center toward  
3        top dead center.

1        9.        The method of claim 8, wherein the exhaust valve remains open until the piston  
2        reaches approximately top dead center.

1        10.      The method of claim 1 further comprising:  
2                selecting a plurality of cylinders for initial firing, selection of each cylinder based  
3        upon the piston of the respective cylinder being located in a predetermined position along its  
4        stroke.

1        11.      The method of claim 1 further comprising:  
2                prior to firing the cylinder selected for initial firing, closing an intake valve.

1        12.      The method of claim 11 further comprising:  
2                prior to firing the cylinder selected for initial firing, closing an exhaust valve.

1        13.      The method of claim 1, wherein the fuel is injected to form a combustible mixture  
2        with a fuel/air ratio approximately stoichiometric.

1 14. The method of claim 1, wherein the fuel is injected via direct injection into the  
2 selected cylinder from an associated injector.

1 15. The method of claim 1, wherein the engine is configured to normally operate on a  
2 four-stroke combustion cycle.

1 16. The method of claim 1 further comprising:  
2 before igniting the uncompressed fuel-air mixture in a selected cylinder, opening an  
3 intake valve to introduce a fresh charge into the selected cylinder.

1 17. The method of claim 1 wherein said selecting, injecting and igniting occurs while the  
2 cylinders are fired according to the predefined normal firing order.

1 18. A method of reducing the speed of an internal combustion engine having a plurality  
2 of cylinders each housing a piston and each having an intake valve and an exhaust valve,  
3 wherein intake and exhaust valve are each controllable independently of engine rotation, the  
4 method comprising:

5 determining a first speed of the engine;  
6 estimating an amount of pumping work sufficient to reduce the speed of the engine to  
7 a second speed;  
8 actuating one or more valves to produce at least part of the estimated amount of  
9 pumping work within the engine; and  
10 reducing the speed of the engine to the second speed.

1 19. The method of claim 18 further comprising:  
2 determining a number of piston strokes sufficient to reduce the speed of the engine  
3 from the first speed to the second speed.

1 20. The method of claim 19 wherein the determined number of piston strokes is a  
2 minimum number of strokes required to reduce the engine speed from the first speed to the  
3 second speed.

1     21.     The method of claim 19 further comprising:

2             determining an amount of pumping work required for each determined number of  
3     strokes to reduce the speed of the engine from the first speed to the second speed.

1     22.     The method of claim 18 further comprising:

2             determining a desired timing of the valves to produce the estimated amount of  
3     pumping work.

1     23.     The method of claim 18 further comprising:

2             determined a desired amount of lift of the valves to produce the estimate amount of  
3     pumping work.

1     24.     The method of claim 22 wherein determining the desired valve timing comprises:

2             dynamically determining the desired valve timing required to produce the estimated  
3     amount of pumping work.

1     25.     The method of claim 22 wherein determining the desired valve timing comprises:

2             accessing pre-stored data indicating the desired valve timing required to produce the  
3     estimated amount of pumping work.

1     26.     The method of claim 18 further comprising:

2             estimating an amount of friction work in one or more of the cylinders of the engine  
3     and wherein the estimated amount of pumping work is a function of the estimated amount of  
4     friction work.

1     27.     The method of claim 18, wherein the second speed is zero and the first speed is a

2     speed within a range of predetermined speeds, for which it has been determined that the  
3     engine may be stopped in one braking stroke using pumping work such that the crankshaft  
4     will stop within a desired range of crankshaft angles.

1 28. The method of claim 18, wherein the second speed is greater than zero, the method  
2 further comprising:  
3 estimating a second amount of pumping work sufficient to reduce the second speed to  
4 zero in one braking stroke; and  
5 after reducing the speed of the engine to the second speed, actuating one or more  
6 valves to produce at least part of the second amount of pumping work within the engine,  
7 reducing the engine speed to zero.

1 29. The method of claim 18, wherein the actuated valves include both intake and exhaust  
2 valves.

1 30. The method of claim 29 further comprising:  
2 opening and then closing all the actuated valves at approximately bottom dead center  
3 and top dead center.

1 31. The method of claim 18, wherein actuating one or more valves to produce the  
2 estimated amount of pumping work comprises:  
3 determining the position of a piston within a cylinder;  
4 opening the valve when the piston is at a first position; and  
5 closing the valve when the piston is at a second position, wherein the first and second  
6 positions depend upon the entering speed of the engine.

1 32. The method of claim 18 wherein estimating the amount of pumping work required to  
2 reduce the speed of the engine from a first speed to a second speed comprises:  
3 estimating the amount of pumping work required to reduce the engine speed to a  
4 second speed of zero such that at least one piston stops at a predetermined location.

1 33. The method of claim 32 wherein the predetermined location is anywhere between 25  
2 and 155 degrees after top dead center.

1 34. A method of stopping an internal combustion engine having a plurality of cylinders,  
2 each cylinder including a controllable valve actuation system for operating one or more  
3 valves of the cylinder, the method comprising:

4 determining a range of speeds in which the engine may be stopped in one braking  
5 stroke using pumping work such that the crankshaft will stop within a desired range of  
6 crankshaft angles; and

7 actuating the valve actuation system to produce pumping work in the cylinders to stop  
8 the engine in one braking stroke when the engine's speed has reached a target speed that is  
9 within the determined range of speeds.

1 35. The method of claim 34 wherein the desired range of crankshaft angles is a range of  
2 positions where at least one piston has sufficient mechanical leverage to rotate the crankshaft  
3 in a clockwise direction.

1 36. The method of claim 34 wherein the desired range of crankshaft angles is a range of  
2 positions where at least one piston has sufficient mechanical leverage to rotate the crankshaft  
3 in a counter-clockwise direction.

1 37. The method of claim 34 further comprising:  
2 prior to actuating the valve actuation system to stop the engine, estimating an amount  
3 of pumping work required to reduced the speed of the engine from a first speed to the target  
4 speed.

1 38. The method of claim 37 further comprising:  
2 determining a number of strokes sufficient to reduce the speed of the engine from the  
3 first speed to the target speed.

1 39. Them method of claim 38 further comprising:  
2 actuating the valve actuation system to produce the estimated pumping work required  
3 to reduce the speed of the engine from a first speed to the target speed.

1 40. The method of claim 38 further comprising:

2 distributing the estimated pumping work evenly among the determined number of  
3 strokes required to reduce the entering speed to the target speed.

1 41. The method of claim 34 further comprising estimating an amount of friction work in  
2 one or more of the cylinders.

1 42. The method of claim 41 wherein estimating an amount of friction work comprises:  
2 prior to actuating the valve actuation system, predicting a residual speed of the  
3 engine;

4 after actuating the valve actuation system, comparing the actual residual speed to the  
5 predicted residual speed; and

6 estimating the friction work based on the difference between the actual residual speed  
7 and the predicted residual speed.

1 43. The method of claim 41 wherein estimating the amount of friction work comprises:

2 applying a minimum amount of pumping work to a cylinder in a stroke;

3 sampling the engine speed during the stroke; and

4 estimating the amount of friction work based on the change in engine speed during  
5 the stroke.

1 44. The method of claim 34 further comprising:

2 after the engine has stopped, adjusting the crank angle of the engine by actuating the  
3 valve actuation system to release a compressed or vacuumed cylinder.

1 45. An internal combustion engine comprising:

2 a cylinder housing a piston attached to a crankshaft;

3 an intake valve that controls the intake of air into the cylinder;

4 an exhaust valve that controls the expulsion of air from the cylinder;

5 an intake valve actuator that controls operation of the intake valve;

6 an exhaust valve actuator that controls operation of the exhaust valve; and

7 a valve control module that, upon receiving a command to stop the engine, adaptively  
8 controls the intake valve actuator and exhaust valve actuator to produce pumping work to  
9 stop the engine such that the crankshaft will stop within a desired range of crankshaft angles.

1 46. The engine of claim 45 wherein the valve control module is configured to, upon  
2 receiving a command to stop the engine, adaptively control the intake valve actuator and  
3 exhaust valve actuator to produce pumping work to reduce the engine from a first speed to a  
4 second speed, wherein the second speed is within a predetermined range of speeds for which  
5 it has been determined that the engine may be stopped in one braking stroke using pumping  
6 work such that the crankshaft will stop within a desired range of crankshaft angles.

1 47. The engine of claim 45 further comprising:  
2 an ignition element disposed at least partially within the cylinder that ignites fuel  
3 within the cylinder;  
4 a fuel injection element disposed at least partially within the cylinder that injects a  
5 suitable amount of fuel into the cylinder; and  
6 an ignition and fuel injection control module that stops the injection and ignition of  
7 fuel upon receiving a command to stop the engine.

1 48. An internal combustion engine comprising:  
2 a cylinder housing a piston attached to a crankshaft;  
3 an intake valve that controls the intake of air into the cylinder;  
4 an exhaust valve that controls the expulsion of air from the cylinder;  
5 an intake valve actuator that controls operation of the intake valve;  
6 an exhaust valve actuator that controls operation of the exhaust valve; and  
7 a starting module that identifies one or more cylinders with pistons in a  
8 predetermined position range, selects the identified cylinders independently of their normal  
9 operating stroke cycles, and fires the identified cylinders.

1 49. The engine of claim 48 wherein the starting module is configured to start the engine  
2 in forward or reverse.



1 50. A method of starting a four-stroke internal combustion engine from rest, wherein the  
2 engine includes a plurality of cylinders each containing a piston, the method comprising:  
3 operating a first number of the plurality of cylinders in a two-stroke cycle that does  
4 not compress fuel-air mixture prior to combustion; and  
5 after sufficient kinetic energy has accumulated in the engine to complete a  
6 compression stroke, then operating simultaneously a second number of the plurality of  
7 cylinders in a normal four-stroke cycle.

1 51. The method of claim 50 further comprising:  
2 ceasing operation of a first number of cylinders in the two-stroke cycle while  
3 continuing operation of a second number of cylinders in a normal four-stroke cycle.

1 52. The method of claim 50 wherein the two stroke cycle includes a first stroke that  
2 introduces a fresh charge and a second stroke that releases combustion residue.

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